

Apollo Bistatic Radar Investigation

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The first bistatic Moon radar experiments were conducted by the Stanford Center for Radar Astronomy, using Lunar Orbiter spacecraft. Apollo not only provides stronger signals, but provides for conduct of the experiment on two frequency bands. The JPL 64-meter-diameter tracking antenna at Goldstone is uniquely suited to the reception of the S-band signals involved, and has been used on both Apollo 14 and Apollo 15 for the bistatic investigation.

I. Introduction

The *Apollo* bistatic radar investigation is a NASA experiment conceived and conducted by the Stanford University Center for Radar Astronomy, utilizing the Jet Propulsion Laboratory 64-meter-diameter Goldstone tracking antenna (DSS 14) and the Stanford 46-meter-diameter antenna.

The experiment uses radio frequency electromagnetic scattering from the lunar surface to determine the principal electrical and structural properties of the lunar crust. Transmissions from the orbiting command and service module (CSM) are directed toward the lunar surface, and oblique reflections of these signals are monitored on the Earth.

II. Description of the Experiment

An S-band experiment is conducted at DSS 14 on 2 GHz simultaneously with a VHF investigation conducted at Stanford on 0.2 GHz. The objectives in collecting bistatic radar data on the lunar surface features are:

- (1) To determine the Brewster angle of the lunar crust. (Brewster angle is the angle of incidence at reflection point where the vertical component reverses phase.)
- (2) To measure the spectral properties of radar echoes from low altitude orbit.
- (3) To gain operational experience with *Apollo* systems and *Apollo* operations as an aid in designing future bistatic experiments.

In the S-band version of this experiment, the CSM radiates a signal on 2287.5 MHz. DSS 14 receives the direct signal and a portion of the signal reflected from the Moon. Because of the polarization and frequency shift resulting from the reflection of the signal by the Moon, the signal energies are separable. The radar data are in a bandwidth ± 10 kHz around the signal reflected from the Moon. The signals are separated into right circular polarization (RCP) and left circular polarization (LCP) by the polarization diversity S-band (PDS) cone, and are fed through separate masers to separate sets of receivers. They are then down-converted and recorded on tape recorders running at high speed. These recordings are taken to Stanford and digitized by a program that scans through a 4-Hz digital filter yielding a listing of power density versus frequency for each polarization. These data are merged with a trajectory to correlate the digitized data with the lunar latitude and longitude of the specular points. The resultant information is a dielectric constant of the Moon and surface roughness. The dielectric constant is a function of the Brewster angle. The surface roughness is a function of the frequency spreading of the signal energy reflected from the Moon. These data are compared with photographs and lunar soil samples and serve to calibrate the technique employed. Thus, when similar experiments are performed on other planets, more precise conclusions can be drawn from RF observations alone or in conjunction with photography.

The signal processing equipment (including interfacing cables) used at Goldstone is the property of Stanford, and is operated by the investigator. The configuration for this is shown in Fig. 1; the Stanford equipment is delineated thereon.

III. Procedures

A. Operations

The investigator, located at DSS 14, has direct two-way voice contact with MSC at Houston, with Stanford University, and with Spaceflight Tracking and Data Network (STDN). He has contact internally with the recorder operator, over whom he has operational jurisdiction. The investigator has direct physical access to the receiver operator for the receiver channels used in the bistatic configuration. He has the prerogative of changing the voltage-controlled oscillator (VCO) and/or synthesizer frequencies for these channels, personally or by verbal instruction, provided that it is not possible thereby to affect normal *Apollo* support.

B. Precalibration Procedures

Following are the detailed procedures that were executed prior to each pass. They served to insure that the equipment and personnel were ready to function correctly.

- (1) Station configured for bistatic radar experiment (see Fig. 1).
- (2) Completed receiver calibrations, checked signal continuity, and routed signals to recorders.
- (3) Made preliminary level checks, set DSIF receiver levels, and set Stanford equipment.
- (4) Produced calibration tapes on both recorders, and simultaneously recorded test signals on tracks 1-6 at the following frequencies: 400 Hz, 1, 5, 10, 20, 50, 90, 120, 150, and 170 kHz.
- (5) Receivers calibrated in 5-dB increments from -80 dbm to threshold. Held 30 seconds at each level, and sent the signals through the Stanford equipment to the recorders. This recording was on the same tape as the calibration recordings, following the test signals.
- (6) Made open-loop synthesizer frequency check and measured predetermined input frequency at recorders.
- (7) Made closed-loop synthesizer frequency check. Locked closed-loop receiver on test signal and measured synthesizer frequency at recorders.
- (8) Changed synthesizer frequencies in (6) and (7), and repeated to test sense of change.

C. Procedures for Frontside Passes Prior to Experiment Orbit of CSM

While the CSM was being tracked on its view period prior to the occultation which preceded the Bistatic Radar Experiment pass, the received signal levels were monitored and compared with the predicted levels, in order that corrections, if necessary, could be determined. Similar observations were made of the frequency.

D. Occultation Period Procedures Prior to Experiment Orbit of CSM

The signal levels in all receivers using noise as a calibration source were observed, as measured in dbm in the 10-MHz distribution amplifier. The open-loop receiver frequencies were set, noise source and coherent test signal

final calibrations performed and recorded on fresh tape, and the tape recorders stopped and readied for the experiment pass.

E. Procedures During Experiment Orbits of the CSM

The tape recorders were started at AOS minus 3 minutes. The closed-loop receivers, on AGC, achieved lock on the signal and the operators awaited instructions to go to MGC. The open-loop receivers, on MGC, acquired the signal. The signal levels were monitored by the operators and the observations compared with the predicted levels.

F. Occultation Procedures Following Experiment Orbit of CSM

Calibration signals for all channels were recorded in fixed increments for both noise source and coherent test signal.

IV. Prepermission Testing

Station internal testing was performed to insure compatibility of equipment, proper installation, and adequacy of instructions. Then, readiness was further confirmed by an end-to-end test in simulated real time, with the following stated objectives: To make the final prelaunch checkout of Stanford hardware, to validate the station configuration, and to familiarize the crews with the configuration and the detailed procedures.

Prerequisites for this test included the final installation of the new open-loop and closed-loop receivers (DSIF nomenclature Occultation Receivers 1 and 2, and Reference Receivers 3 and 4); finalized location and installation of the cabinet for the Stanford equipment; checkout of the Receiver Mode Selectors to insure simultaneous distribution of LCP and RCP 50-MHz maser output signals to all the receivers involved; intercom terminal for the investigator installed; special high-speed configuration of the tape recorders checked out; and adequate spares for peculiar equipment on hand.

In general, the detailed operating procedures mentioned above were followed in the conduct of the test, divided into three phases:

Phase 1. A normal station countdown was conducted, with the special interconnections carefully verified.

Phase 2. The investigator called out in real time the steps to be taken in putting test signals through the receivers and Stanford equipment. Signals from *Pioneer* spacecraft were used, as well as from test signal generators.

Phase 3. In addition to the steps in Phase 2, the signals were then recorded in a full dress rehearsal.

To insure that DSIF staff and management were kept abreast of developments in the preparation and testing for the experiment, a readiness report and a post-test report were required of the Station Director. These reports covered status of prerequisites, recapitulation of training, times of conduct of the various phases, names of key personnel involved, description of failures or anomalies, comments of key personnel, and a certification of readiness.

Upon completion of the test, the Stanford equipment and cables were left in place, and were not disturbed until the completion of the flight experiment. The tape recordings made during the test were made available to the investigator, who returned with them to Stanford.

V. Summary

The S-band portion of the *Apollo* Bistatic Radar Investigation, conducted by NASA-JPL facilities, required an unusual amount of preparation and attention to detail because of the nonstandard configuration and procedures. Through the use of detailed specifications and instructions all requirements have been met, and the reports prepared by the investigator (see Refs. 1-4) indicate that the operation was completely satisfactory, yielding results about an order of magnitude better than any previously obtained from similar attempts.

References

1. Howard, H. T., and Tyler, G. L., "Bistatic-Radar Investigation," in *Apollo 14 Preliminary Science Report*, NASA SP-272. National Aeronautics and Space Administration, Washington, 1971.
2. Howard, H. T., and Tyler, G. L., "Bistatic-Radar Investigation," in *Apollo 15 Preliminary Science Report*, NASA SP-289. National Aeronautics and Space Administration, Washington, 1971.
3. Howard, H. T., *Stanford University Bistatic Radar Experiment Apollo S-170*. Stanford University, Calif. (undated).
4. Tyler, G. L., and Howard, H. T., *Sample Bistatic Radar Spectra from Apollo 14*. Stanford University Office Memorandum, Mar. 4, 1971.

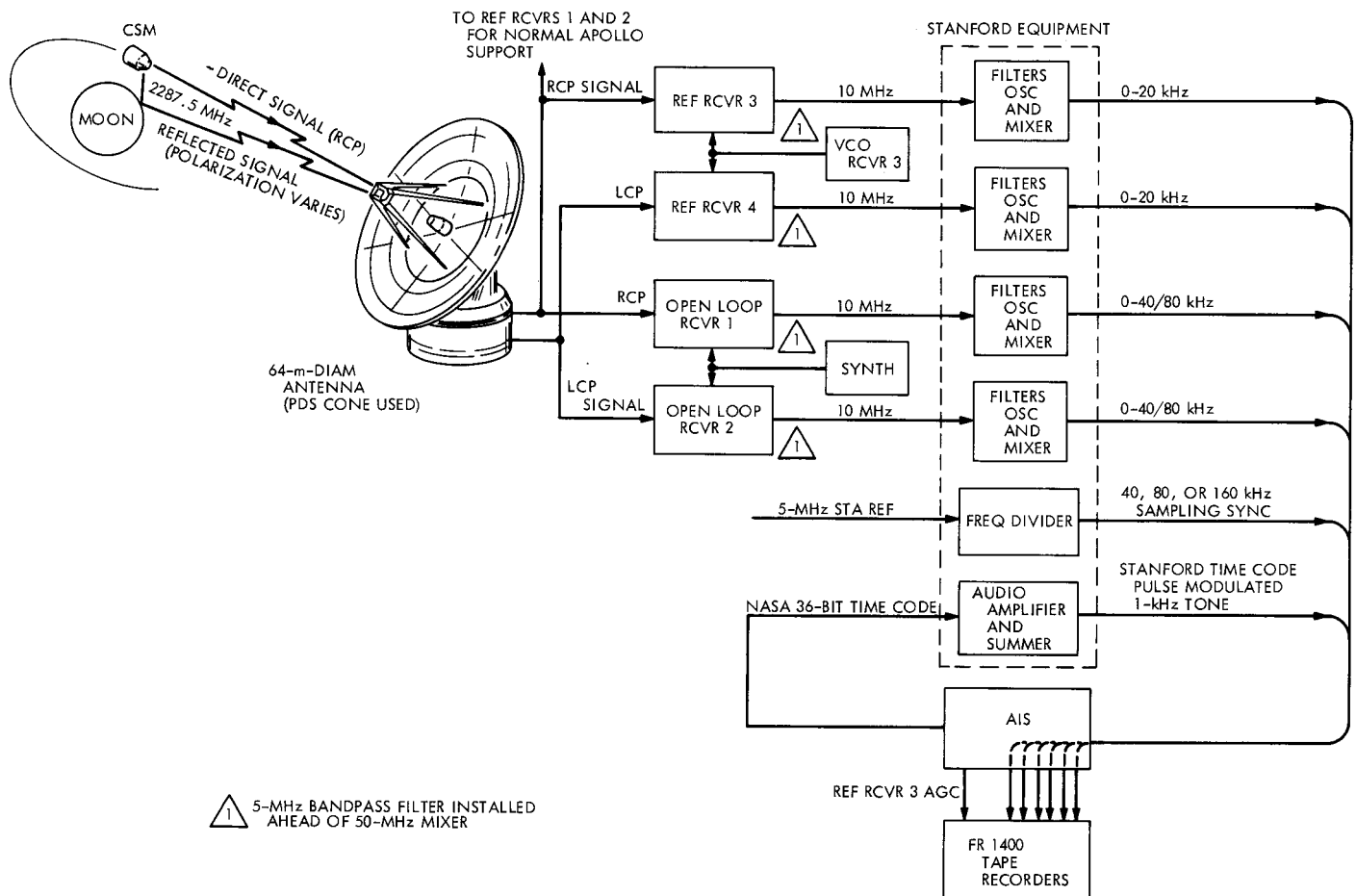


Fig. 1. DSS 14 configuration for S-band bistatic radar experiment